Physics Results by the Vanderbilt Group From the PHENIX Experiment
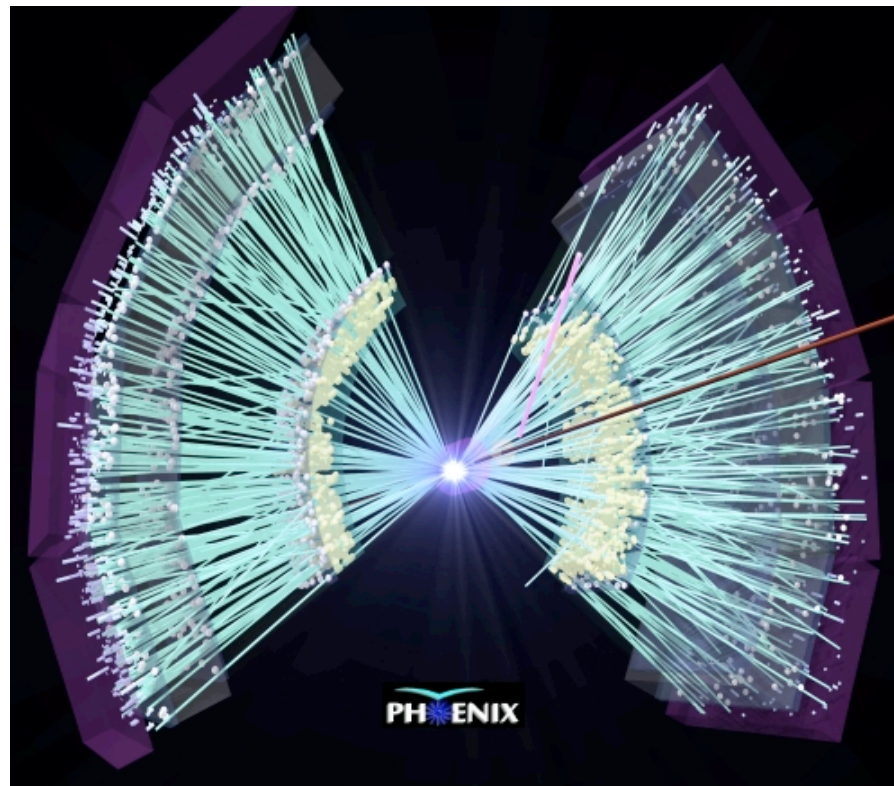
The Hunt for the Quark Gluon Plasma
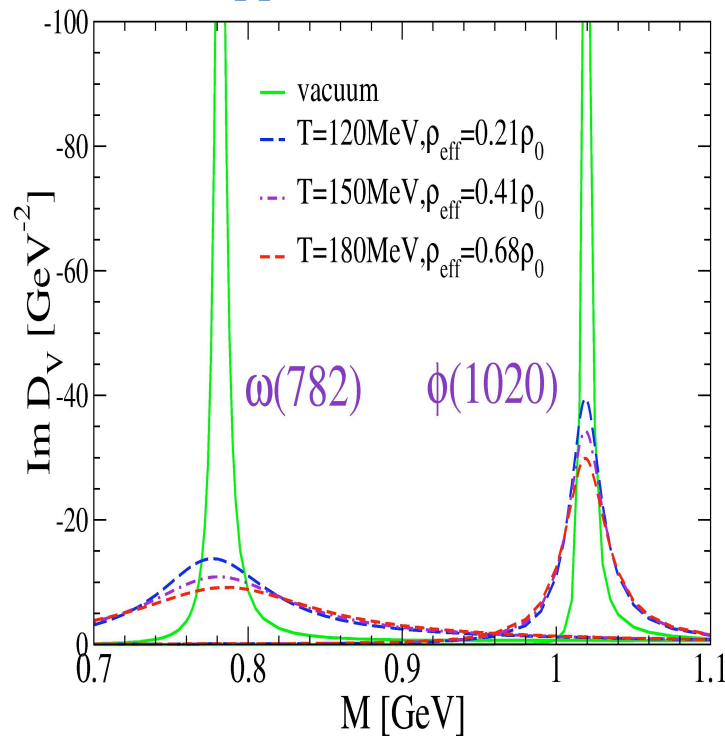**(for more information visit http://www.phenix.bnl.gov)**

A Very Special Meson: φ
The Swiss Army Knife of QGP Probes

R. Rapp nucl-th/0204003

A theoretical prediction of how the widths of the ω and φ mesons might change as the medium temperature is raised past the chiral symmetry restoration temperature

φ **Meson as a Special Probe for RHI Collisions**
- s-s bound state (little initial state strangeness)
- sensitive to strangeness production
- small interaction cross-section with nucleons ==> retains information on production state

φ **Properties**
- Mass = 1.019456 +/ 0.0000020 GeV/c^2 (close to that of the proton)
- Breit-Wigner Width = 4.26 +/- 0.05 MeV (comparable to detector resolution)
- Interesting decay modes
  - φ → K$^+$K$^-$ (BR = 49.2%)
  - φ → e$^+$e$^-$ (BR = 2.96 x 10^{-4})
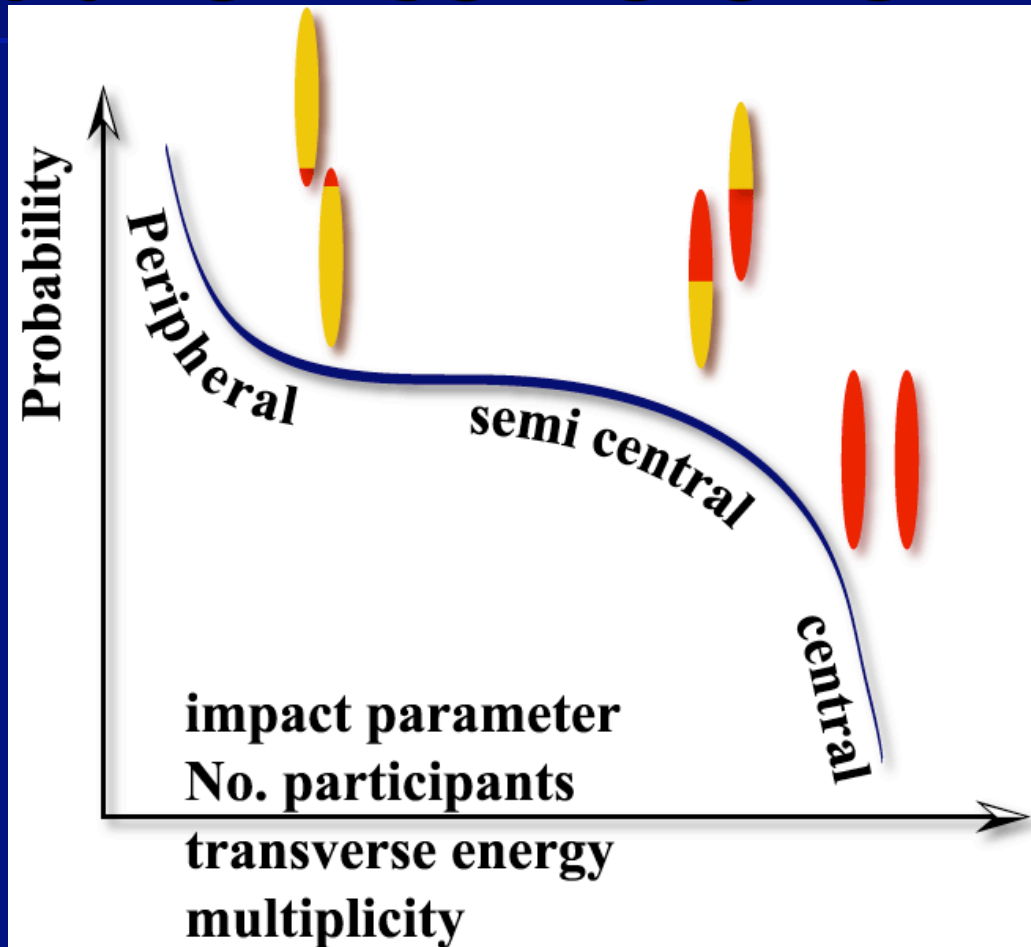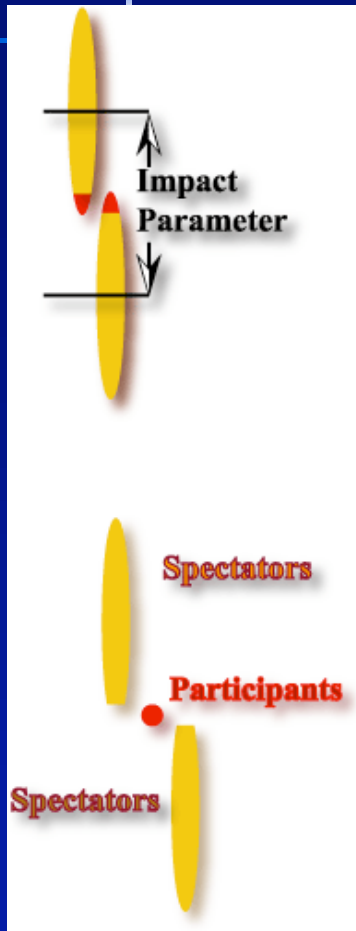 - φ → μ$^+$μ$^-$ (BR = 2.87 x 10^{-4})

φ **Experimental Observables**
- Yield (dN/dy) as a function of transverse mass (m$_T$) and collision centrality
- Line shape parameters Mass and Width
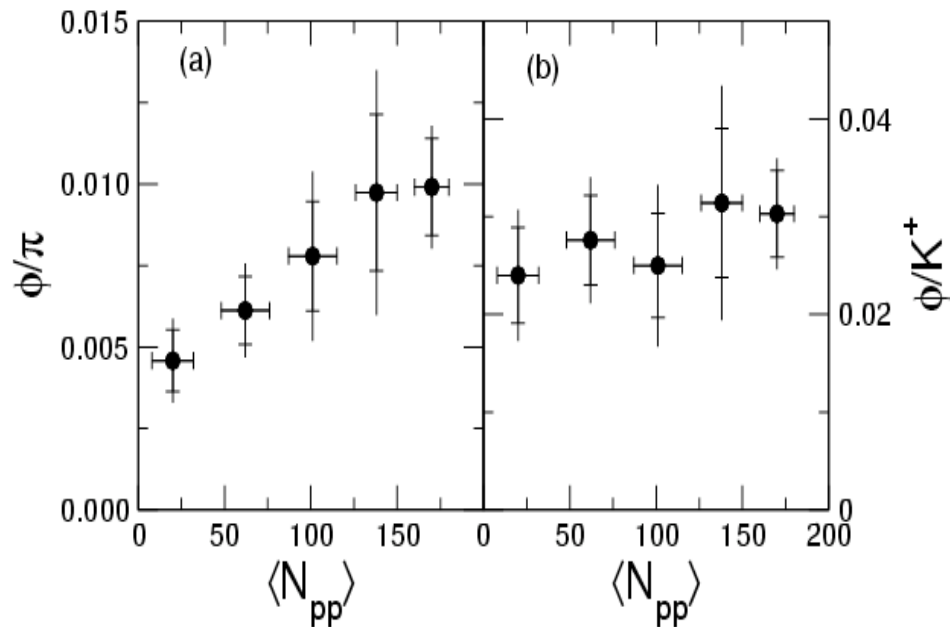
Main Physics Questions
- Do the BRs change from the PDG values?
- Do the line shape parameters vary?
- Do the yields vary from expectations?

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# How to pick the most head-on collisions

φ Production Topics

E917 Fiducial Yields for φ in Au+Au at √s_NN = 4.87 GeV (AGS Fixed Target)

The observed yield of the φ relative to π appears to increase as a function of collision centrality in Au+Au collisions at the AGS.

Is the same behavior observed at RHIC? Are their differences between the d+Au and the Au+Au production ratios at RHIC?

"Baryon Anomaly" in Au+Au at √s_NN = 200 GeV (RHIC)
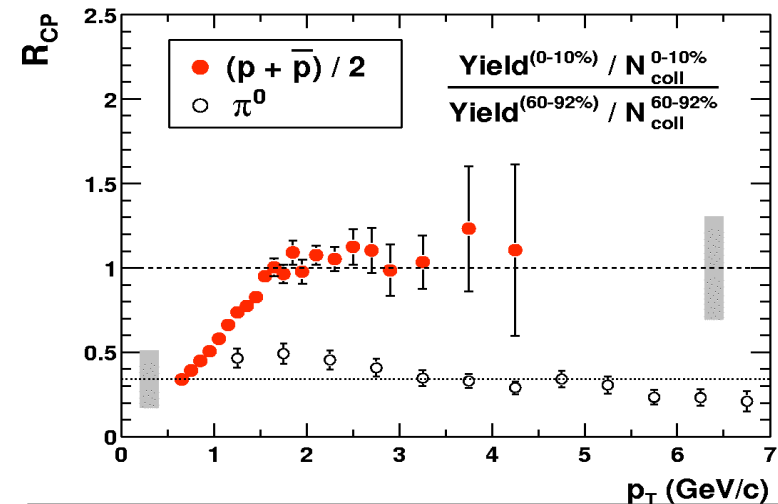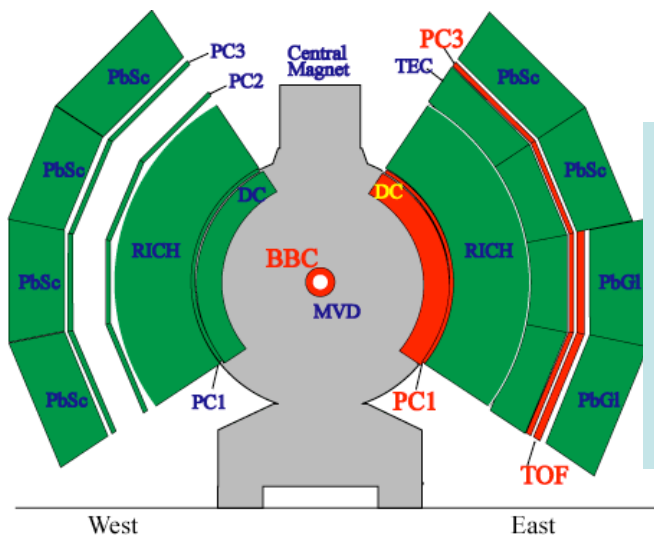

R_{CP} :Central/Peripheral Ratio dN/dy scaled by the number of collisions

Strong suppression of π^0 yields above $p_T \sim 2$ GeV/c but no suppression for proton and antiproton at intermediate $p_T \sim (2\text{-}5$ GeV/c)

Is this anomaly a mass effect, or an effect of the meson/baryon difference between the π and the proton?

4

Detecting the φ in PHENIX

momentum resolution

$$\sigma_p/p \sim 1\% \oplus 1\% \, p$$

Leads to ~1 MeV pair resolution for φ ->K$^+$K$^-$ Compare Γ_ϕ = 4.24 MeV
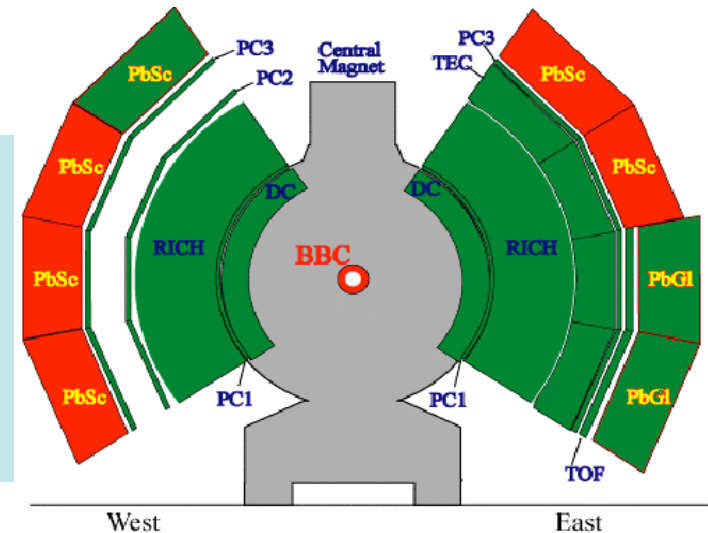
φ->K$^+$K$^-$ uses TOF-TOF, EMCal-EMCal, and TOF-EMCal
East Arm only for Run2
East + West Arms for Run3

φ->e$^+$e$^-$ uses RICH, EMCal-EMCal in East-West, East-East, and West-West

TOF resolution 120 ps

EMCal resolution 450 ps
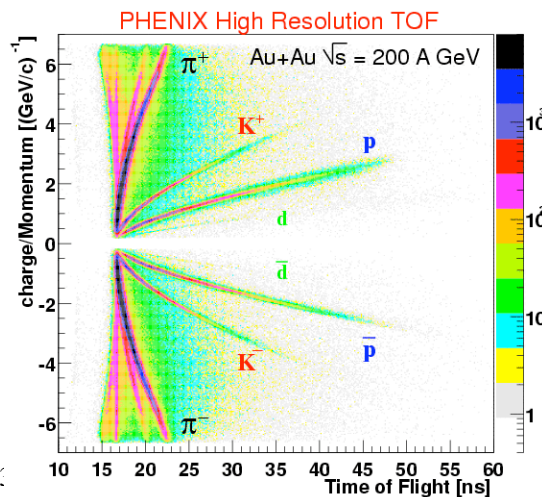
Physics

Charles F. Maguire

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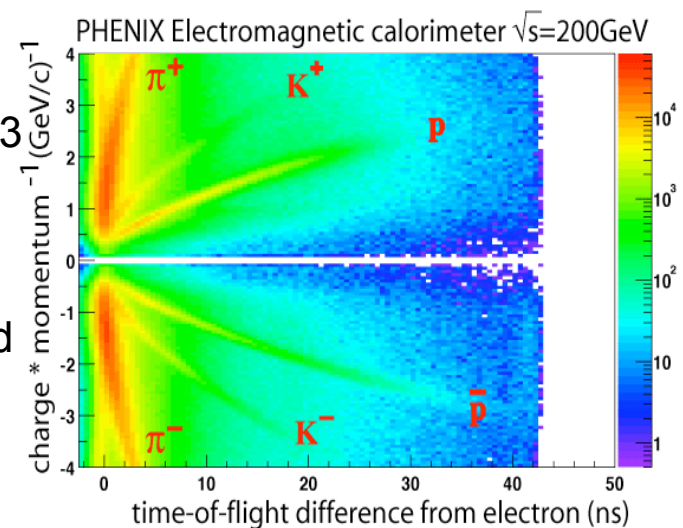
Data Samples

- **Data sets:** Au+Au 200 GeV, data taken during RHIC Run2 (2001/2002)
  d + Au 200 GeV, data taken during RHIC Run3 (2003)

- **Statistics:** analyzed 20 M minimum bias (MB) events for Run2
  analyzed 54 M minimum bias events for Run3

Au + Au at $\sqrt{s_{NN}}$ = 200 GeV
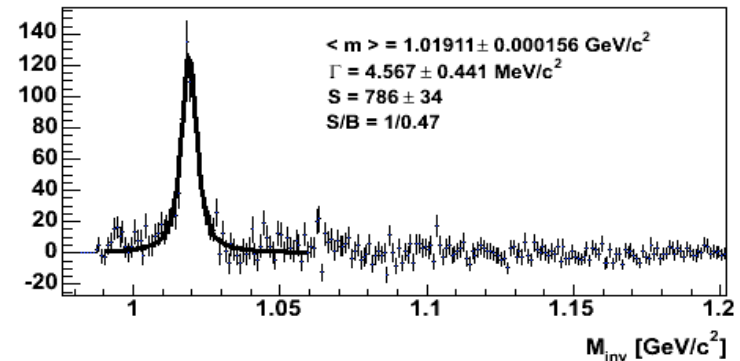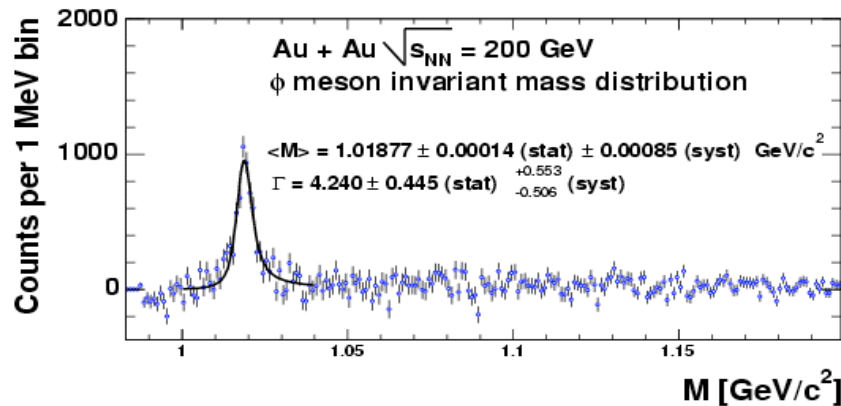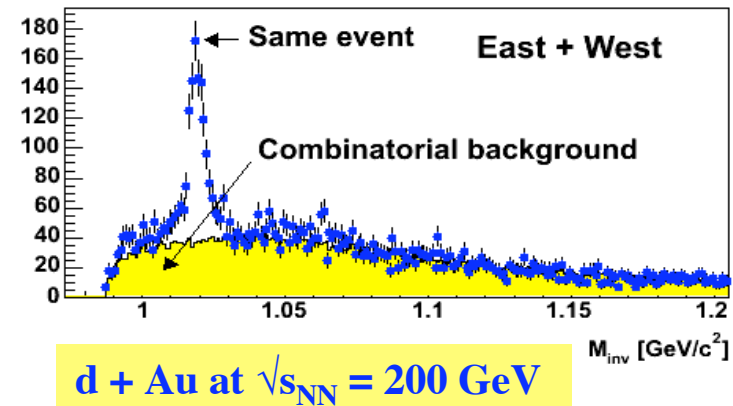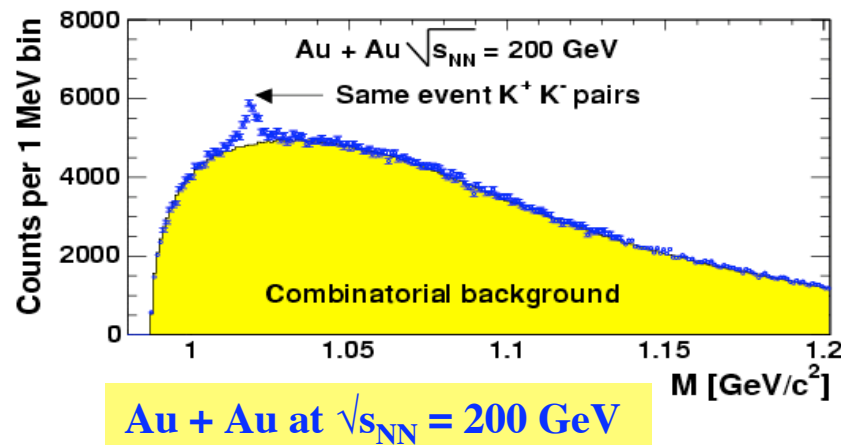
d + Au at $\sqrt{s_{NN}}$ = 200 GeV

Line Shape Analysis for the ϕ
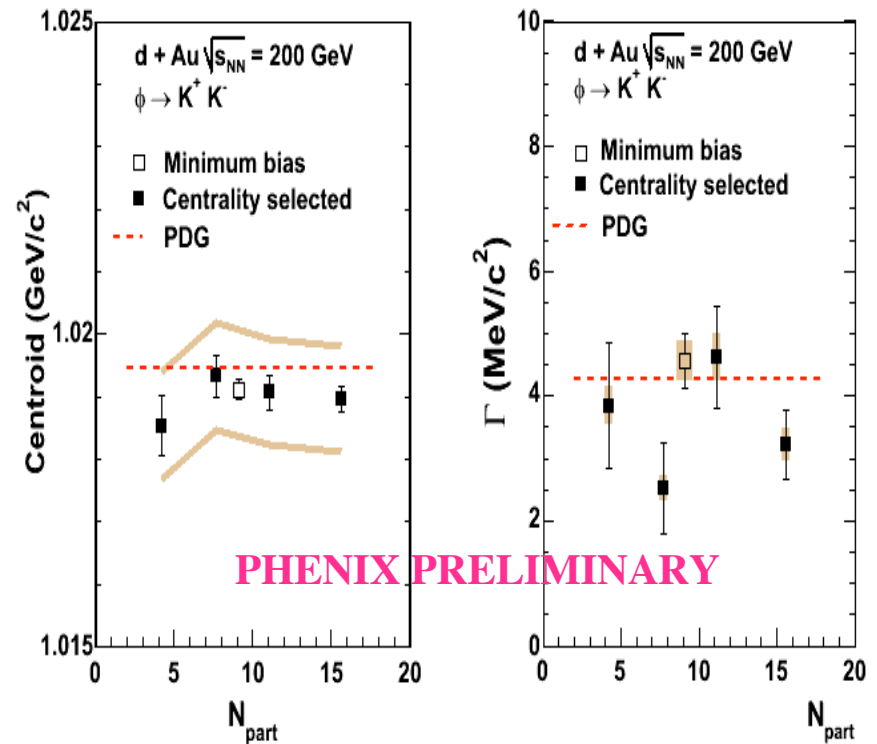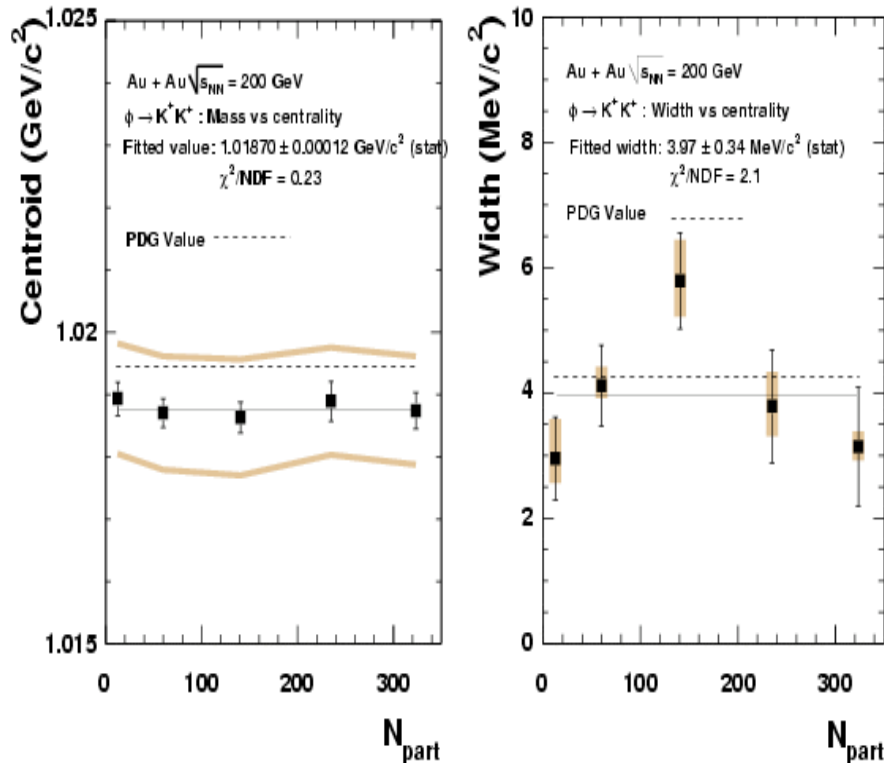
M_ϕ = 1.01870 +/- 0.00012 GeV/c²
Γ_ϕ = 3.97 +/- 0.34 MeV/c²
Consistent with PDG values
No evidence of a centrality dependence

M_ϕ(min bias) = 1.01911 +/- 0.00016 GeV/c²
Γ_ϕ (min bias) = 4.57 +/- 0.44 MeV/c²
Consistent with PDG values
No evidence of a centrality dependence

Yield Analysis for the ϕ in Au + Au Compare to π^0 and protons in R_{CP}

$$R_{cp} = \frac{\text{Yield } (0 - 10\%)/N_{coll}(0 - 10\%)}{\text{Yield } (40 - 92\%)/N_{coll}(40 - 92\%)}$$
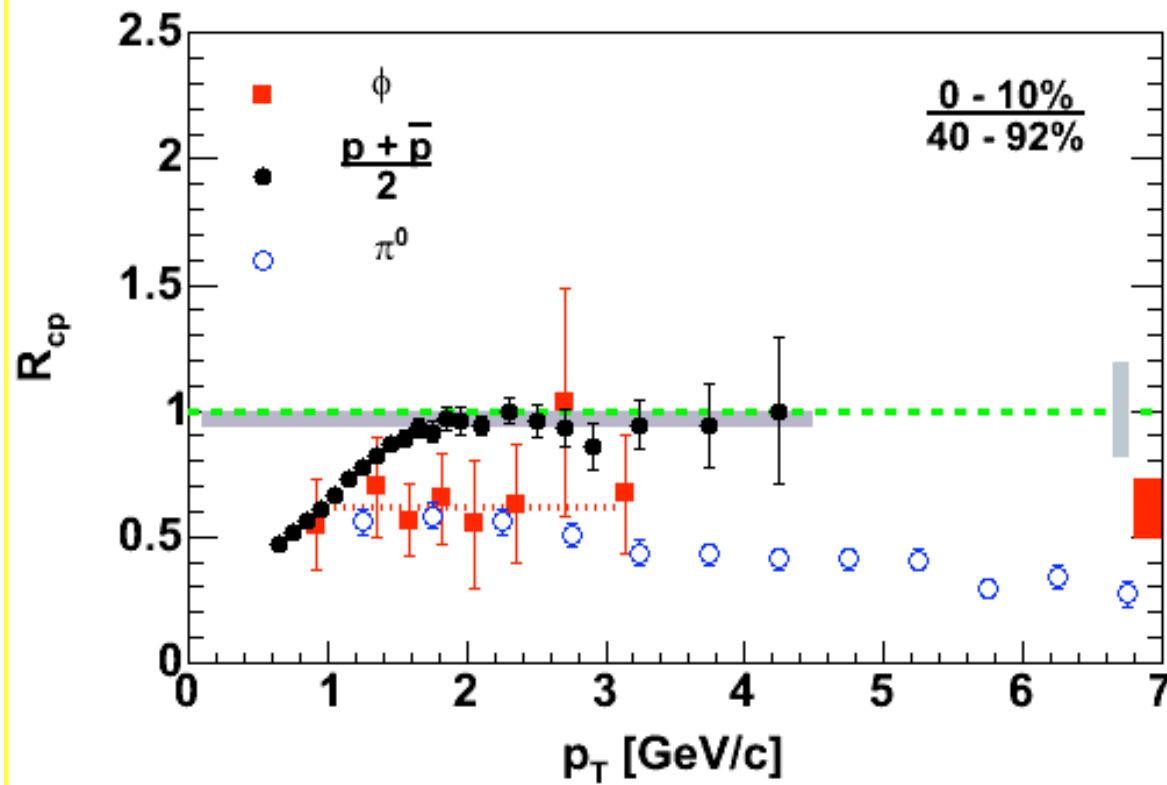
Similar behavior for ϕ and π

Baryon anomaly not a mass effect

Consistent with quark coalescence models

Yield Analysis for the φ in d + Au
Compare K^+K^- and e^+e^- Channels

φ→ e^+e^- d+Au (MB)
√s = 200 GeV

Mixed Background

Counts per 10 MeV/c²

S ~ 120
S/B = 1/4

e^+e^- invariant mass (GeV/c²)

$1/2\pi m_T dN/dm_T dy$ $(GeV/c^2)^{-2}$

φ → K^+K^- Min Bias
φ → e^+e^-

Consistent yields in K^+K^- and e^+e^- channels

PHENIX Preliminary

$M_T(GeV/c^2)$

Physics 300: February 15, 2005   *Charles F. Maguire*
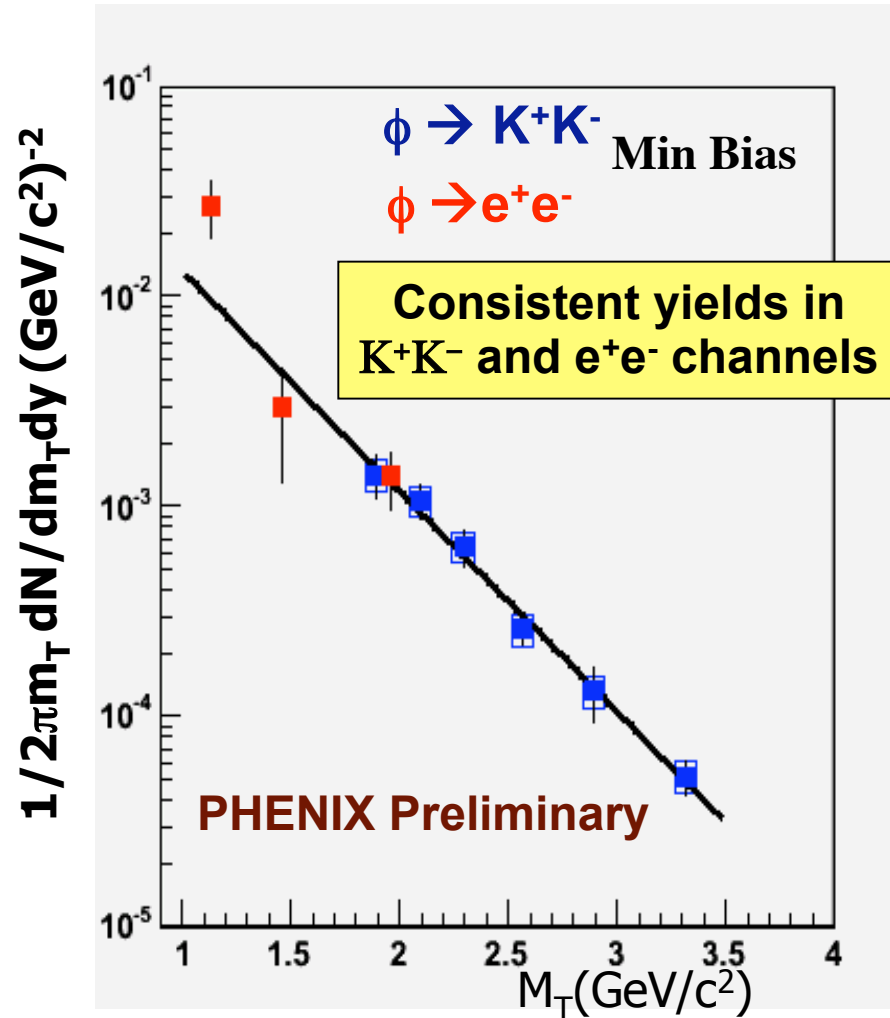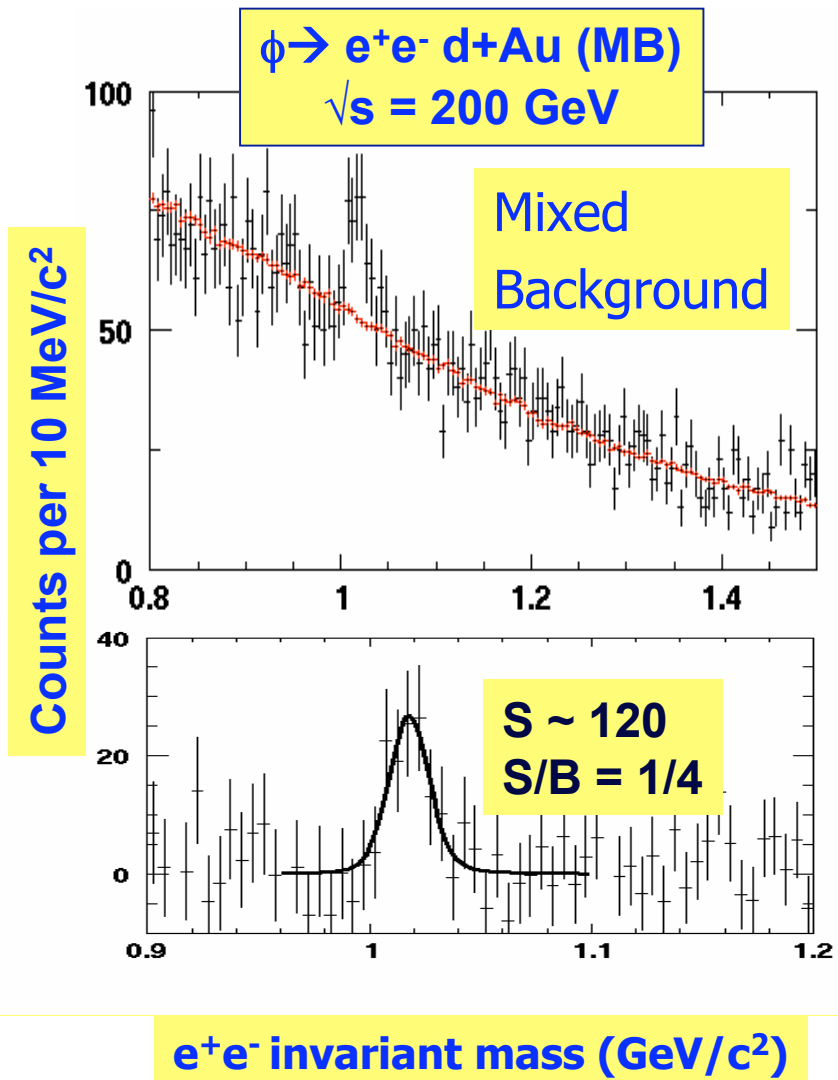
Compare Yields for the φ in d+Au and Au+Au at $\sqrt{s_{NN}} = 200$ GeV

Lower range of N_{part}
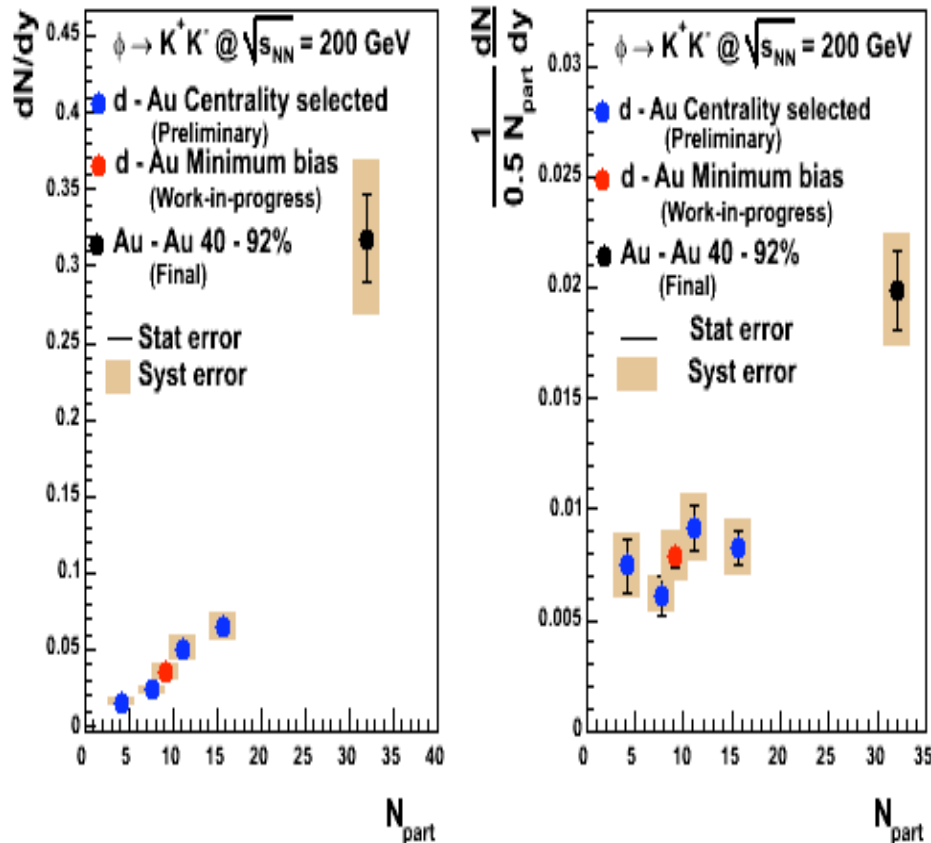
Complete range of N_{part}
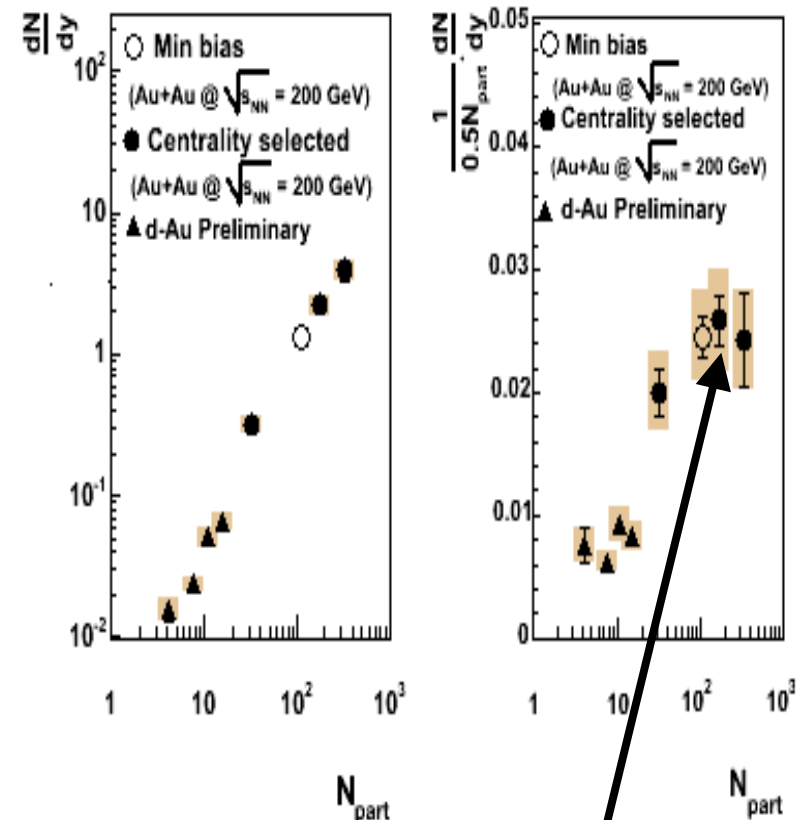
The φ yield per participant in Au+Au is at least a factor of 3 higher than in d+Au !

Future ϕ Analysis Efforts in PHENIX Immediate Opportunities for Students

*Awaiting the Discovery Announcement of the sQGP
The <u>strongly coupled</u> Quark Gluon Plasma
(Apparently the most perfect liquid of all)
Perhaps to be made at QGP2005 Meeting in Budapest
And appearing in a Physics Today issue in the next year*

Does the φ Manifest Elliptic Flow? Expect to get answer from Run4 data

y

x

$\vec{p}_y$ **Elliptic Flow**

$\vec{p}_x$

□ v_2 of π   PRL 91(2003) 182301

● v_2 of p/p-bar

v_2

p_T (GeV/c)
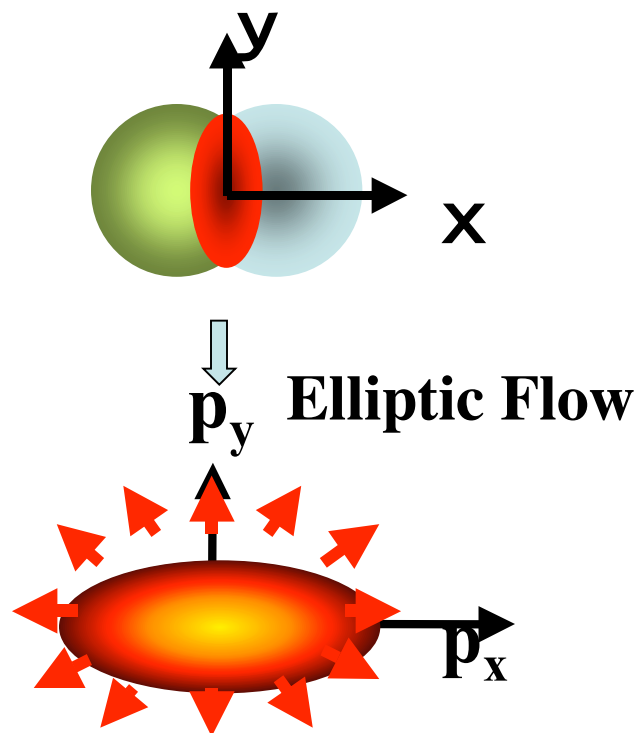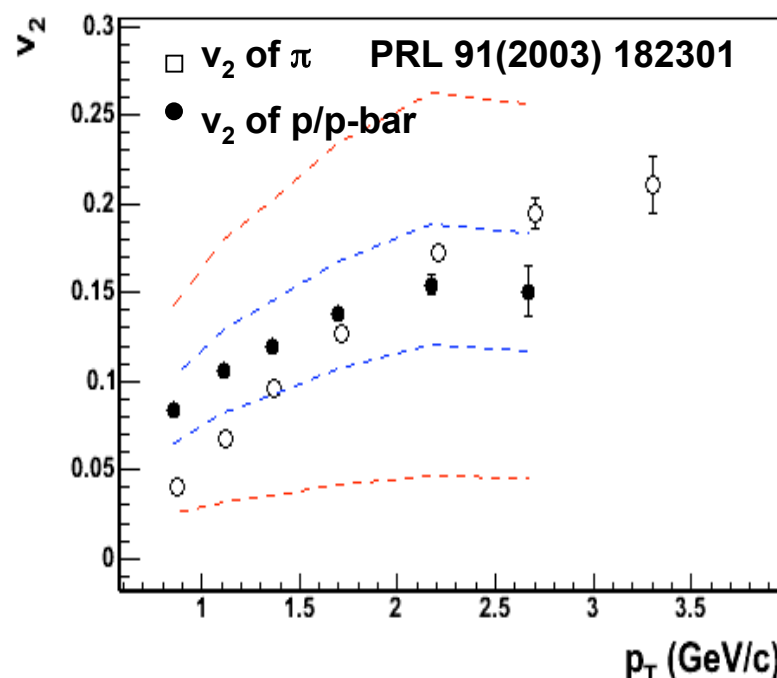
For non-central collisions the initial spatial anisotropy transforms to an anisotropy in the emission directions in the reaction plane. This emission anisotropy is scaled as a v_2 coefficient in an azimuthal Fourier expansion.

Run2 (Au + Au):
Predicted statistical error (~70%) on φ [assuming $v_2(\phi) = v_2(\pi)$]

Run4 (Au + Au) @ 10x Run2
Predicted statistical error on
φ [assuming $v_2(\phi) = v_2(\pi^-)$]

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Physics 300: February 15, 2005   *Charles F. Maguire*

Does the φ Manifest Global QGP Polarization?
Hope to get answer from Run4 data

y (reaction plane direction)

X (impact parameter)

Z (beam)

y

K⁻

φ

x

K⁺

z

Angle α between decay particle and reaction plane
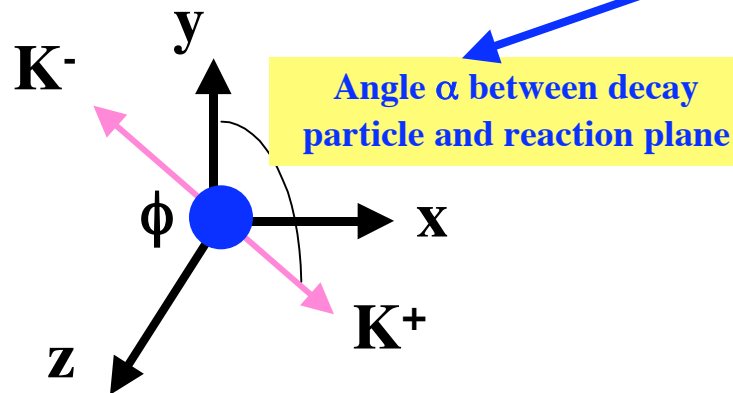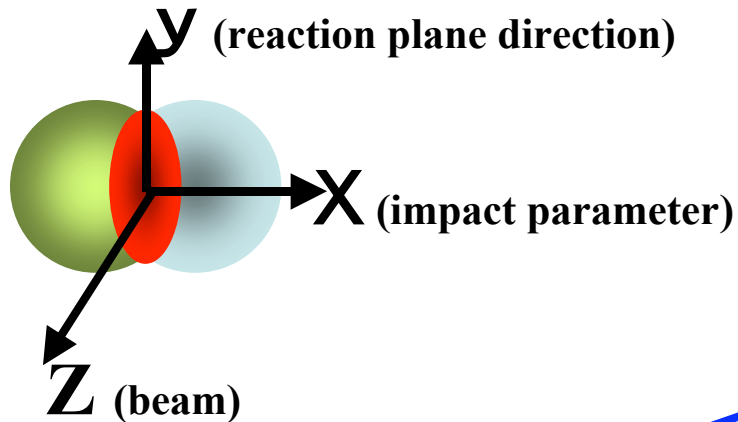
Rest frame decay of the φ
Kaon kinetic energy 16 MeV

Global Polarization Signal of the QGP
Liang and Wang, nucl-th/04011101 (11/25/04)

Vector meson decay particles aligned
w.r.t. reaction plane direction in rest frame
Alignment depends on hadronization scenarios
Induces a decay angular distribution

$$W(\alpha) = 0.75[\ (1 - \rho_{00}) + (3\rho_{00} - 1)\cos^2\alpha\ ]$$

ρ_{00} **is spin density matrix element**
$$0 \leq \rho_{00} \leq 1$$
ρ_{00} = 1/3 **means no polarization**
ρ_{00} **may be parameterized as a function of** φ p_T
$$\rho_{00} = \rho_{000} + (1/3 - \rho_{000})(2/\pi)\text{atan}(p_T/a_0)$$
ρ_{000} **= polarization at** p_T **= 0, a_0 = 0.5 GeV/c**

Question: Is the PHENIX detector sensitive to a polarization signal in the φ, given the fiducial acceptance of PHENIX and the actual reconstruction resolutions in PHENIX?

Does the φ Manifest QGP Polarization? Simulation Studies of PHENIX Sensitivity

Alpha Angle with no Reconstruction Errors

φ → K^+ + K^- Reconstructed in PHENIX for 0.50<p_T<2.5 GeV/c

φ are polarized along reaction plane direction

Polarization according to arXiv:nucl-th/0411101v1

$W(\alpha) = N_0[(1-\rho_{00}) + (3\rho_{00} - 1)\cos^2(\alpha)]$, input constant ρ_{00} = 0.50

Fit ρ_{00} = 0.51

Entries	11571
Mean	90.93
RMS	57.2
χ^2 / ndf	53.194 / 43
Norm	602.93 ± 5.62
rho00	0.51049 ± 0.00712

Alpha Angle: rest frame angle of decay kaon with respect to reaction plane (deg)

1) Reconstruct 11.6K φ decays
Exact PHENIX geometry model
Perfect momentum reconstruction
Perfect reaction plane angle
Recover input polarization parameter
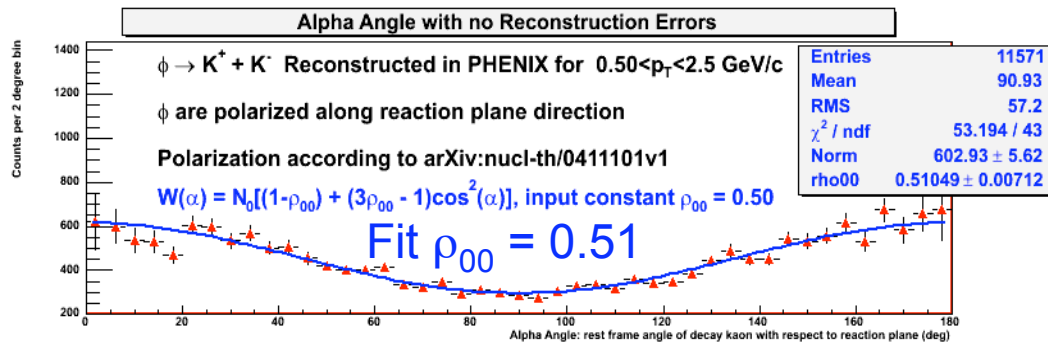
Alpha Angle with Momentum Reconstruction Resolution

Fit ρ_{00} = 0.51

Introduce momentum reconstruction resolution effect

Entries	11571
Mean	91.63
RMS	57.66
χ^2 / ndf	57.011 / 43
Norm	603.15 ± 5.62
rho00	0.51369 ± 0.00712

Alpha Angle: rest frame angle of decay kaon with respect to reaction plane (deg)
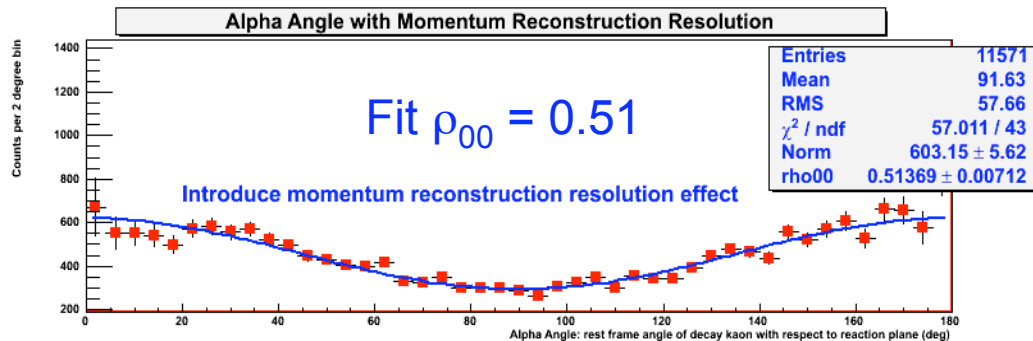
2) Realistic momentum reconstruction
Still perfect reaction plane angle
No change in fit parameter

Alpha Angle with Momentum and Reaction Plane Reconstruction Resolutions

Fit ρ_{00} = 0.47

Introduce reaction plane angle resolution (σ = 27°) effect

Entries	11571
Mean	92.25
RMS	56.62
χ^2 / ndf	54.575 / 43
Norm	603.03 ± 5.62
rho00	0.47458 ± 0.00718

Alpha Angle: rest frame angle of decay kaon with respect to reaction plane (deg)
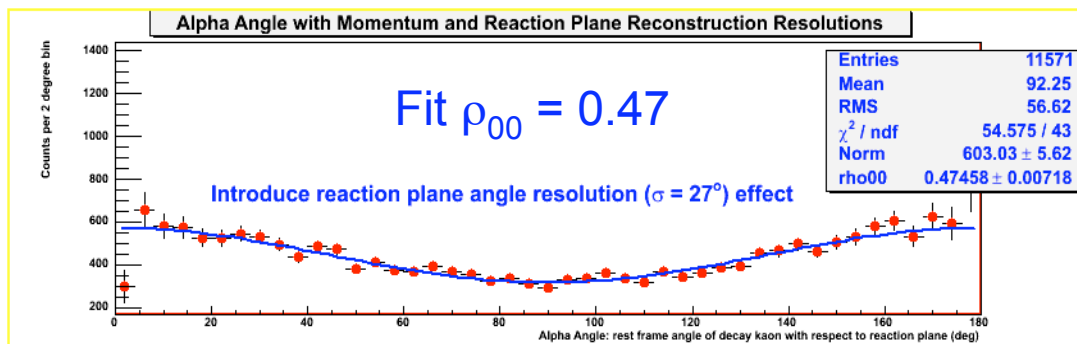
3) Realistic momentum reconstruction
Realistic reaction plane angle
Only small change in fit parameter

Answer: It looks promising to detect a significant φ polarization pending S/B simulations

PHENIX High p_T Particle Identification Upgrade Vanderbilt Project (tour by Hugo Valle)

Aerogel *& MRPC Time-of-Flight*

- Together with the Aerogel, TOF and RICH, we can extend the PID to 10 GeV/c
- **Coverage: ~ 4 m² in PHENIX west arm**

AEROGEL Cherenkov detector:
- n = 1.0113.
- Completed full installation for Run5.

Additional TOF counter is required for K/p separation below 5 GeV/c.

Decided to use MRPC technology for TOF taking advantage of STAR's experiences

Extension of Charged Hadron PID Capability
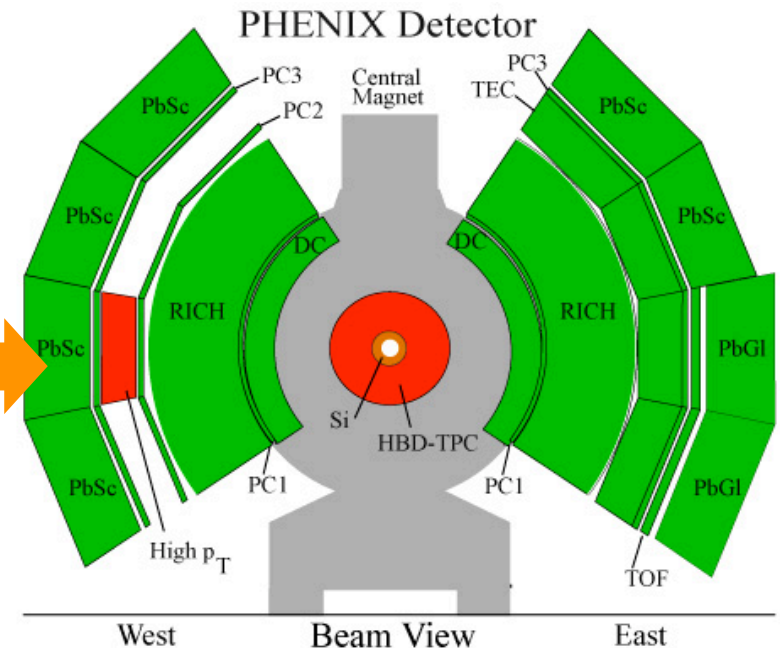# Will be operational in PHENIX for RHIC Run6

		Pion-Kaon separation	Kaon-Proton separation
TOF	σ~100 ps	0 - 2.5	- 5
RICH	n=1.00044 γth~34	5 - 17	17 -
Aerogel	n=1.01 γth~8.5	1 - 5	5 - 9

With TOF

AEROGEL : (n=1.0114, threshold= 10% of Max. Np.e.)

Momentum [GeV/c]	0.5	1. 2. 2.5	3. 3.5	4. 4.2	5. 5.5	6. 6.5	7.	~10. (momentum limit)
π		TOF / AEROGEL				RICH		
K		TOF / TOF(proton) ∩ AEROGEL		AEROGEL ∩ RICH				
p		TOF	AEROGEL(∩ RICH)					

Aerogel _together with TOF_ can extend PID range to 10 GeV/c

Without TOF, no K-proton separation at p_T < 5 GeV/c

Added reach in K momentum will significantly increase the signal of the φ in PHENIX

MRPC: Multi-gap Resistive Plate Chamber

- A stack of resistive plates (glass) with electrodes stuck on the outside.
- Internal glass plates electrically floating, take and keep correct voltage by electrostatics and flow of electrons and ions produced in gas avalanches.
- Resistive plates transparent to fast signals, induced signals on external electrodes is sum of signals from all gaps (also, equal gain in all gaps)
- Operated in avalanche mode for TOF detector.

The MULTIGAP Resistive Plate Chamber

Essentially a stack of resistive (glass) plates with electrodes stuck on the outside

Pick-up electrode
Mylar
Carbon layer
glass
glass
glass
glass
glass
glass
Carbon layer
Mylar
Pick-up electrode

- H.V.

Gas gaps ~ 250 μm

+ H.V.
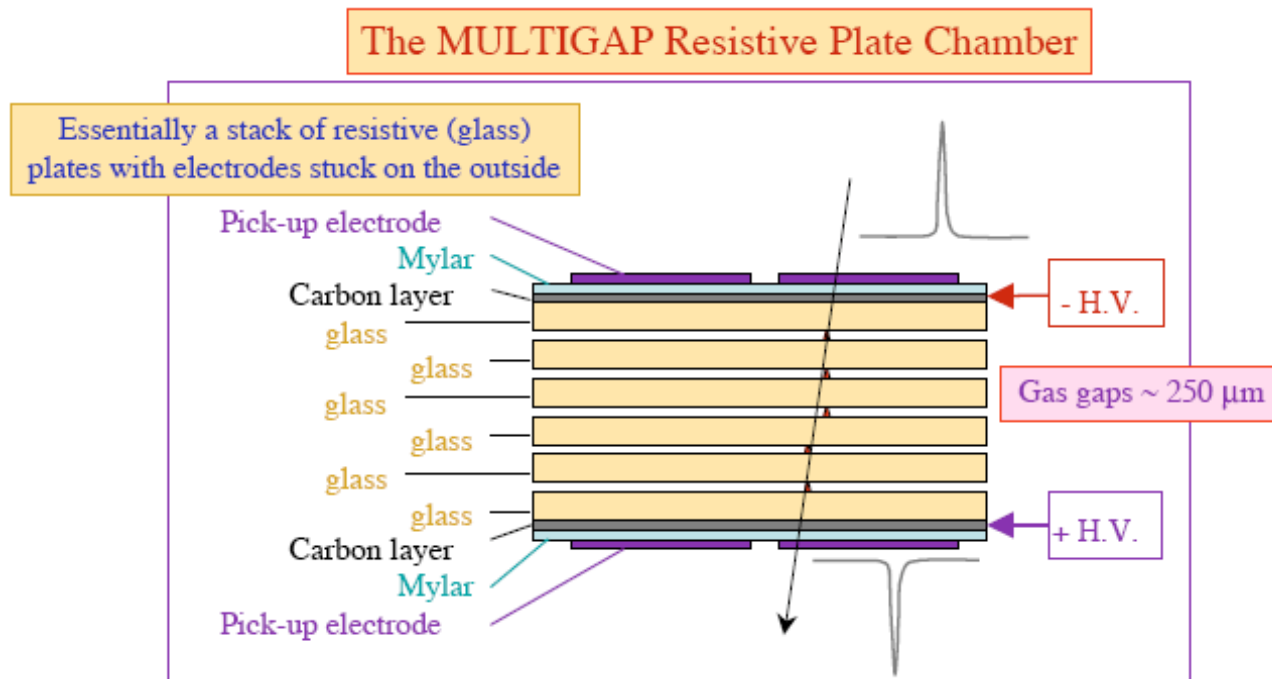
From QM2001 (ALICE-TOF) poster by Crispin Williams.

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Because of Dalitz and photon conversion electrons, the Combinatoric Background (CB) in the φ di-electron channel is painfully high

φ→ e⁺e⁻ d+Au (MB)
√s = 200 GeV

Mixed Background

Counts per 10 MeV/c²

S ~ 120
S/B = 1/4

e⁺e⁻ invariant mass (GeV/c²)

φ→ e⁺e⁻ Au+Au (MB)
√s = 200 GeV

Run2

PHENIX Preliminary

Solution:
Hadron Blind Detector near vertex which will reject Dalitz and conversion pairs
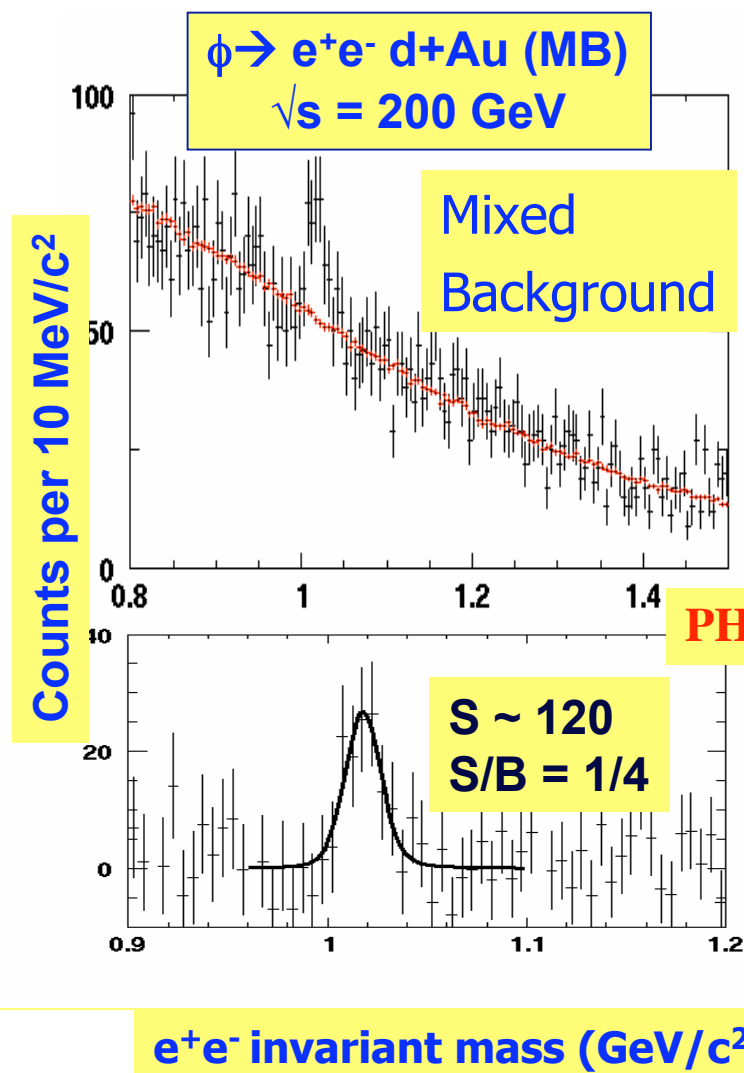
e⁺e⁻ invariant mass (GeV/c²)
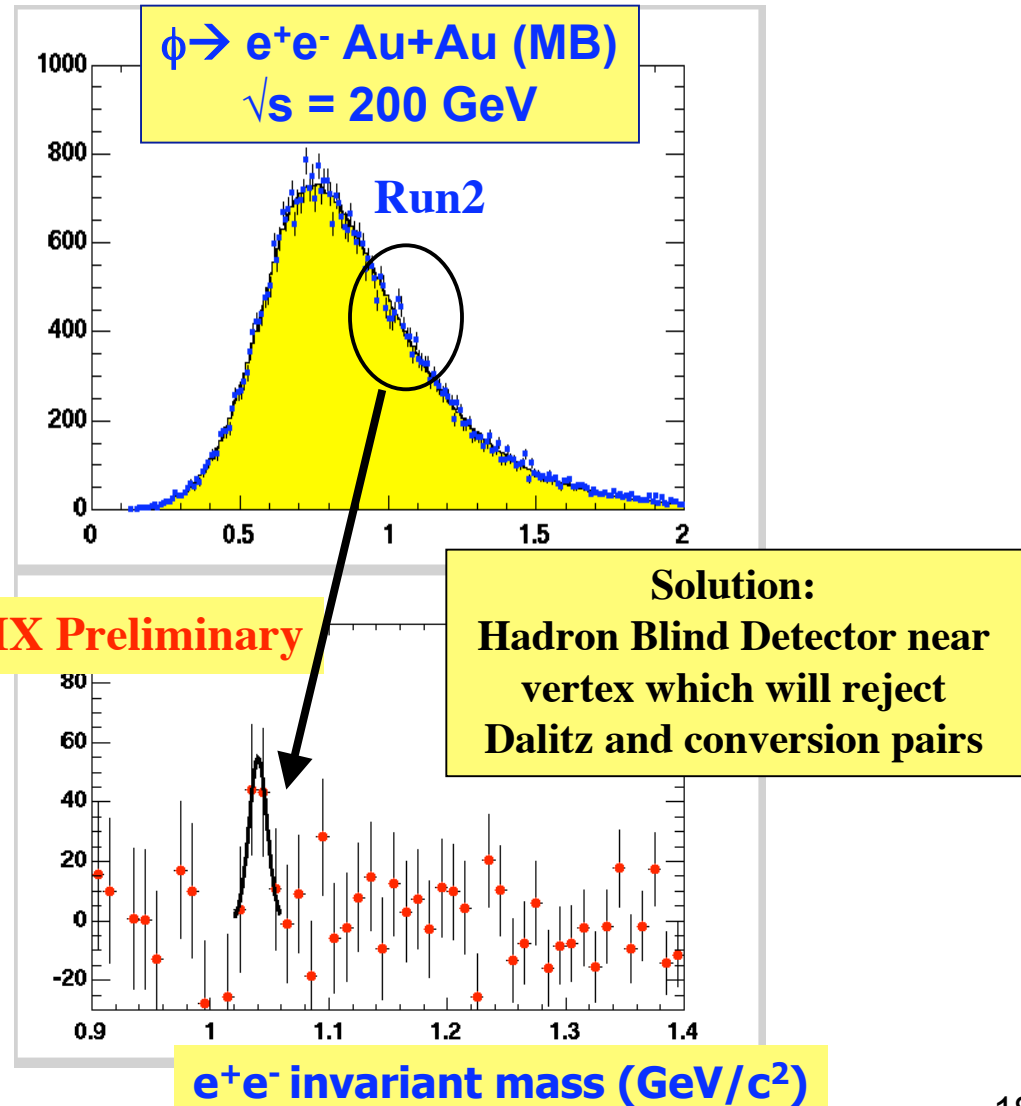
Proposed Hadron Blind Detector for Electron Background Suppression

Detector Modeled in GEANT Simulation Factor of 50 reduction in CB for Au+Au !

e+e- invariant mass specta, Au+Au, 200 GeV, dN/dy$_{ch}$ = 650

- ■ Combinatorial background (HIJING, HBD, no rejection)
- ＊ Combinatorial background from charm (PYTHIA)
- ● Combinatorial background (HIJING, HBD rejection)
- — Total background (HIJING+PYTHIA, HBD rejection)
- - - Signal without charm (EXODUS: π^0, η, η', ρ, ω, ϕ)
- — Total signal (EXODUS+PYTHIA)
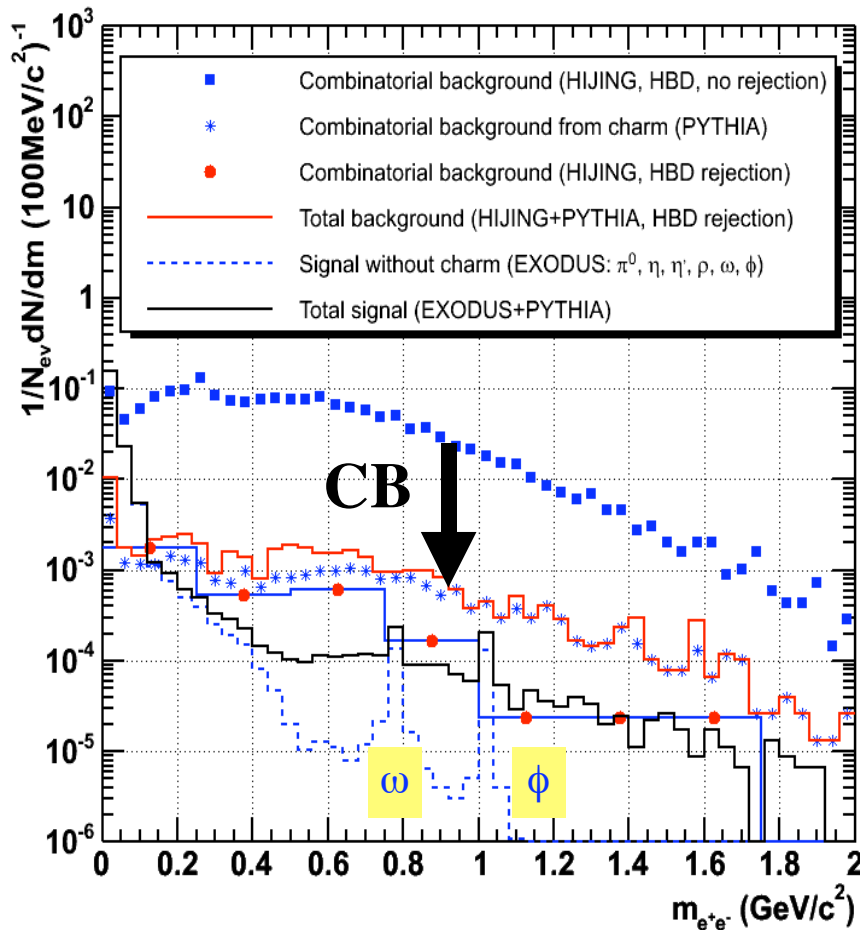
Detector Inserted into PHENIX Vertex Region
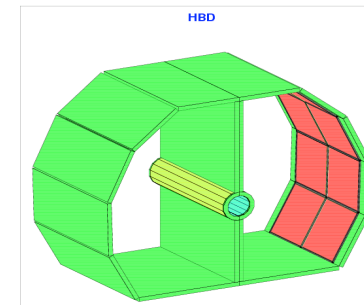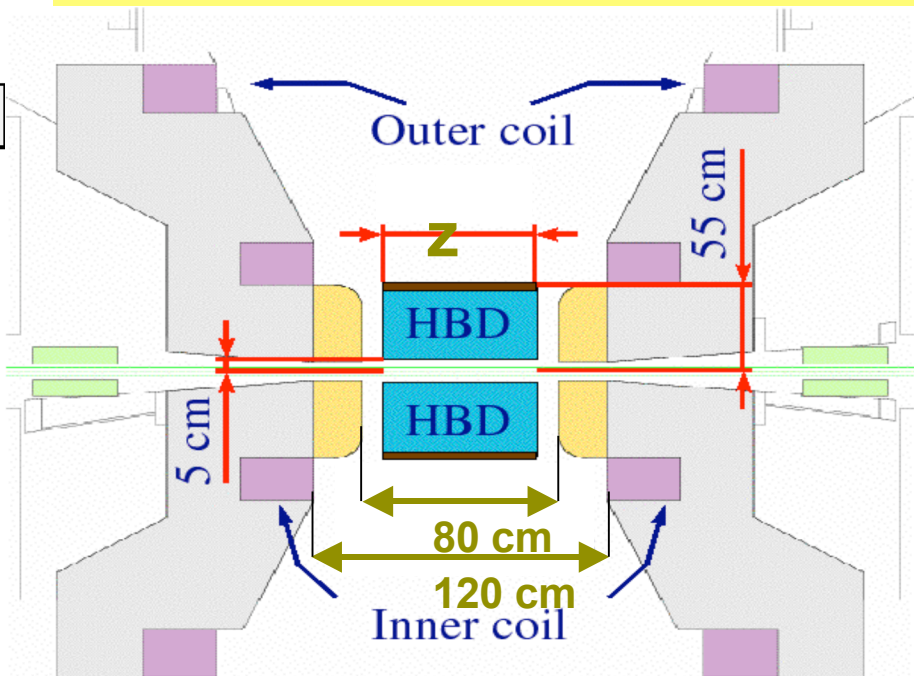
Full scale HBD Prototype design
Prototype proposed for Run6 installation

A (1:2)

B (1:2)

23
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995,8
937,8
R49,4
R69,05
569
597,9

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10.1
10.2
11

Complete set of engineering drawings available at:
https://www.phenix.bnl.gov/phenix/WWW/p/draft/ravini/hbd_drawings/prototype

RHIC Hadron Blind Detector	תכנון מכשירים Instrument Design Weizmann Institute of Science	Updated by	Date
Orderd By Particle Physics		Designed by Lilia	Date 27/09/2004
Project Part Part Name 3981.01- Assembly1		Material	Quantity

Summary and Outlook

- **PHENIX measured $\phi \rightarrow K^+K^-$ in Au+Au and d+Au at $\sqrt{s_{NN}} = 200$ GeV**
  - ○ **No mass shift is observed as a function of centrality in either system**
    Mass centroid is constant to within less than 1 MeV
  - ○ **No width broadening is observed as a function of centrality**
    Width broadening is less than 2 MeV
  - ○ **Yield of ϕ per participant in Au+Au jumps (~3x) compared to d+Au**
    Ratios ϕ/π and ϕ/K are larger (~2x) in Au+Au compared to d+Au
  - ○ **R_{cp} of the ϕ in Au+Au is consistent with that of the π^0 rather than the protons**
    Indicates that the baryon anomaly is not a mass effect

- **PHENIX measured $\phi \rightarrow e^+e^-$ for minimum bias d+Au**
  - ○ **Transverse spectrum consistent with that of $\phi \rightarrow K^+K^-$**

- **Future effort in PHENIX for the ϕ**
  - ○ **Expect to see 10x as many ϕ (i.e. ~50K) in Run4 Au+Au; (Run5 Cu+Cu in progress)**
    Should enable measurement of the v_2 of the ϕ, and possibly a ϕ polarization
  - ○ **Detector upgrades will significantly extend range of ϕ measurements and e^+e^-**
    For Run6 (2006)

Brazil University of São Paulo, São Paulo
China Academia Sinica, Taipei, Taiwan
  China Institute of Atomic Energy, Beijing
  Peking University, Beijing
France LPC, University de Clermont-Ferrand, Clermont-Ferrand
  Dapnia, CEA Saclay, Gif-sur-Yvette
  IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
  LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
  SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany University of Münster, Münster
Hungary Central Research Institute for Physics (KFKI), Budapest
  Debrecen University, Debrecen
  Eötvös Loránd University (ELTE), Budapest
India Banaras Hindu University, Banaras
  Bhabha Atomic Research Centre, Bombay
Israel Weizmann Institute, Rehovot
Japan Center for Nuclear Study, University of Tokyo, Tokyo
  Hiroshima University, Higashi-Hiroshima
  KEK, Institute for High Energy Physics, Tsukuba
  Kyoto University, Kyoto
  Nagasaki Institute of Applied Science, Nagasaki
  RIKEN, Institute for Physical and Chemical Research, Wako
  RIKEN-BNL Research Center, Upton, NY
  Rikkyo University, Tokyo, Japan
  Tokyo Institute of Technology, Tokyo
  University of Tsukuba, Tsukuba
  Waseda University, Tokyo
S. Korea Cyclotron Application Laboratory, KAERI, Seoul
  Kangnung National University, Kangnung
  Korea University, Seoul
  Myong Ji University, Yongin City
  System Electronics Laboratory, Seoul Nat. University, Seoul
  Yonsei University, Seoul
Russia Institute of High Energy Physics, Protovino
  Joint Institute for Nuclear Research, Dubna
  Kurchatov Institute, Moscow
  PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
  St. Petersburg State Technical University, St. Petersburg
Sweden Lund University, Lund

12 Countries; 58 Institutions; 480 Participants*

* as of January 2004

USA Abilene Christian University, Abilene, TX
  Brookhaven National Laboratory, Upton, NY
  University of California - Riverside, Riverside, CA
  University of Colorado, Boulder, CO
  Columbia University, Nevis Laboratories, Irvington, NY
  Florida State University, Tallahassee, FL
  Florida Technical University, Melbourne, FL
  Georgia State University, Atlanta, GA
  University of Illinois Urbana Champaign, Urbana-Champaign, IL
  Iowa State University and Ames Laboratory, Ames, IA
  Los Alamos National Laboratory, Los Alamos, NM
  Lawrence Livermore National Laboratory, Livermore, CA
  University of New Mexico, Albuquerque, NM
  New Mexico State University, Las Cruces, NM
  Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
  Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
  Oak Ridge National Laboratory, Oak Ridge, TN
  University of Tennessee, Knoxville, TN
  Vanderbilt University, Nashville, TN

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